# Spring 2006
# Industry Study

# Final Report
# *Electronics Industry*


**<u>The Industrial College of the Armed Forces</u>**

National Defense University

Fort McNair, Washington, D.C.  20319-5062

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# ELECTRONICS INDUSTRY 2006 STUDY REPORT

**ABSTRACT:** The electronics industry, led by the semiconductor sector, helped trigger one of the most significant economic, military, and social transformations since the Industrial Revolution, and there is every sign the tremendous rate of technological change will continue apace. Some industry observers have called for government intervention to reverse the overseas migration of U.S. semiconductor fabrication plants, to boost U.S. global competitiveness by funding basic research, and to encourage more college graduates in engineering and science fields. Government action to preserve strategic access to semiconductor producers is clearly needed to ensure DoD electronic systems can be built without compromising sensitive technology, though every effort should be made to minimize the cost by using commercial avenues whenever possible. While government actions to support basic research and improve competitiveness are warranted, other actions that attempt to counter global market forces would not succeed.

Lt Col Robert Bell, ANG
Ms. Martina Carroll-Garrison, Dept. of Army
CDR Daniel Donovan, USN
Lt Col John Fisher, USAF
Lt Col Paul Guemmer, USAF
COL Robert Harms, USA
Lt Col Timothy Kelly, USAFR
LTC Mattie Love, USA
CDR James McReynolds, USN
CAPT Ralph Ward, USN
Ms. Dee Woodard, Dept. of Homeland Security

Col Charles Howe, USAF, Faculty
CAPT David Belt, USN, Faculty

## Places Visited

**Domestic**
American Electronics Association, Washington DC
Applied Materials, Sunnyvale, CA
Argon ST, Fairfax VA
BAE Systems, Nashua, NH
Defense Advanced Research Projects Agency, Washington DC
Defense Microelectronics Agency (DMEA), Sacramento, CA
DoD Anti-Tamper Program, Washington DC
Electronics Design Automation Consortium, San Jose, CA
Intel, Santa Clara, CA
Micron Technologies, Inc., Manassas, VA
MIT-Lincoln Laboratories, Lexington, MA
National Council on Competitiveness, Washington DC
National Research Council, Washington DC
National Security Agency, Jessup, MD
National Semiconductor, Santa Clara, CA
National Venture Capital Association, Washington DC
Raytheon Integrated Defense Systems, Andover, MA
Semi, Washington DC
Semiconductor International Association, Washington DC
Tessera, San Jose, CA
Virginia Semiconductor, Fredericksburg, VA

**International**

**Taiwan:**
Aerospace Industrial Development Corporation
Chung Cheng Institute of Technology, National Defense University, Taiwan
Chung Shan Institute of Science and Technology
Industrial Technology Research Institute
Powerchip Semiconductor Company
Taiwan Semiconductor Industry Association
Taiwan Semiconductor Manufacturing Company (TSMC)
UMC (Taiwan)

**India:**
Bharat Electronics, Ltd., Ghaziabad
Centillium India Private Ltd.
Cypress Semiconductor - India
Director General of Quality Assurance, Electronics Section, Ministry of Defense (New Delhi)
International Institute of Information Technology (IIIT) – Bangalore
Qualcomm – India
Software Technology Parks of India (STPI)
Synopsis – India

**Singapore:**
Singapore Defense Science and Technology Agency
Semi - Singapore

## Introduction

Just as the Industrial Revolution dramatically transformed nearly every aspect of 19th century social, economic, and military life, today's Information Revolution is producing equally momentous global changes. The electronics industry, led by astounding developments in semiconductor devices, played a central role in igniting this latest revolution, and enabled tremendous global advances in economic productivity, quality of life, and defense system technology. Organizations in the United States pioneered many of these advances, and their leadership in semiconductor developments directly supported the nation's commanding lead in global economic and military strength in the post-Cold War era. However, some analysts are concerned that the U.S. advantage is diminishing, and that future economic and military security may be at risk. Industry groups and defense experts have called for strong government action to prevent a further decline in competitive advantage.

This paper provides the results of an electronics industry study conducted by a student group at the Industrial College of the Armed Forces (ICAF). The group focused on the vital semiconductor sector since developments there have historically driven the electronic industry's growth. Extensive interviews conducted with semiconductor industry leaders and analysts in the U.S. and Asia provided a wide range of perspectives – both domestic and global, and from inside and outside the defense establishment. The following sections summarize the group's findings on the industry's current condition and outlook, and provide policy recommendations for addressing challenges within this essential industry without resorting to protectionism or other harmful measures. Specific recommendations are included for improvements in U.S. research and development programs, human capital policies, and defense programs. As will be seen, while there are significant reasons for optimism, there are no simple solutions.

## Industry Defined

### *Background*

Semiconductor materials such as silicon are not good electrical conductors on their own, but with the addition (or "doping") of other elements, can become either good conductors or insulators of electron flow. These properties make it possible to construct transistors using semiconductor materials; these act as switches that alternatively conduct or prevent current flow in response to an external input. By doping semiconductors with the appropriate materials in microscopic areas and connecting these areas with extremely small metal pathways, the result is an extraordinarily complex integrated circuit with millions of transistors. In order to imagine the relative scale involved, an advanced circuit is similar to shrinking a major city's road grid down to an area the size of a fingernail, except that the city's streets would originally be three inches wide (Anonymous industry interviews, May 2006).

Following the transistor's invention at Bell Labs in 1947, the federal government played a leading role in developing the U.S. semiconductor industry through significant investments in research and development (R&D) for Cold War defense programs, and in the education of engineers and scientists to support the developing high-tech industries (Flamm, 2005). Defense programs remained the primary customer for semiconductor products in the early decades until the personal computer and other commercial devices became popular in the early 1980's. Since

then, popularity exploded for cell phones, game systems, and countless other semiconductor-driven consumer electronics devices. Subsequently, the consumer market rapidly overtook the defense industry, and today U.S. defense acquisitions command only about 1 to 2 percent of the global market (Defense Science Board, 2005).

Understanding the semiconductor industry's scope requires a review of the basic stages of the value chain, which starts with the conversion of sand into pure silicon and ends with the assembly, testing, and packaging of completed chips for use in an electronic device. Figure 1 (below) depicts the chain's basic stages (Howe, 2006). Consistent with the trend towards horizontal integration, many firms specialize in one part of this chain:

> Chip design typically uses Electronic Design Automation (EDA) software tools to create and test the tremendously complex chip designs. Companies that specialize in this sector are known as "fab-less," since they do not fabricate chips from their designs. These companies may use "pre-packaged" designs provided by EDA firms as modules in a larger circuit; this process greatly reduces the time to market for complex new products (Anonymous industry interviews, May 2006). Design-for-manufacturing (DFM) software tools have become common in the EDA world to support increasingly complex manufacturing processes, where mistakes in mask development and manufacturing incur unacceptably large costs. The design sector is generally less profitable than the mask and fabrication sectors. EDA firms typically earn revenue by licensing their software to designers, and one analyst noted the industry would like to shift to a business model based on revenue for every unit manufactured (Anonymous industry interview, May 2006).
>
> Mask generation uses photolithography processes to create an image for each layer of the chip design. Several firms stated mask generation is the most profitable part of the manufacturing process; masks for advanced circuits may cost as much as $1 million, and up to 40 masks are required per circuit (Anonymous industry interviews, May 2006). A high degree of confidence in the new circuit's design is thus required before firms commit to mask generation.
>
> Wafer fabrication employs sophisticated fabrication machines ("tools") that use the masks to transfer each layer of the chip design to the silicon wafer using photolithography processes. Subsequent steps deposit doping materials or other metals within microscopic target areas, followed by etching, oxidation, or other steps to complete the layer. The tools repeat similar complex processes for each layer in the design. This step of the value chain is particularly capital-intensive due to the very expensive fabrication tools. A new fabrication facility can cost $3 billion or more. Firms that specialize in the fabrication process are called foundries, while vertically integrated firms that both design and produce chips are called Integrated Device Manufacturers (IDM).
>
> Packaging connects the chip electrically and physically to the electronic device. While older packages typically increased the chip's overall size considerably, consumer electronics designs now demand significant size reductions in packaging.

Testing processes conducted frequently throughout the manufacturing cycle are crucial for detecting errors as early as possible in order to minimize the associated costs. The testing of the packaged chip is the final step before shipment to an Original Equipment Manufacturer (OEM).

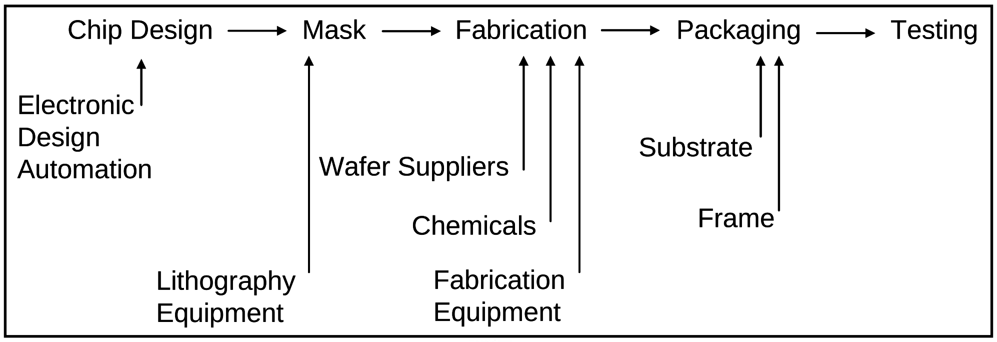


**Figure 1: Semiconductor Industry Value Chain**

Semiconductor chips are rarely sold to the final consumer directly, but form an essential input to countless other industries, including Information Technology (IT) systems, automobiles, healthcare devices, defense systems, and many others (SIA, 2004).

Many semiconductor firms specialize in a particular semiconductor product sector. For example, some firms focus on Dynamic Random Access Memory (DRAM) and NAND flash memory chips, while others produce analog devices that typically act as sensors or input/ output devices needed for many consumer devices such as cell phones. However, a number of firms are still able to maintain a profitable presence in multiple sectors.

### *Globalization Impacts*

Semiconductors and the Information Revolution helped to enable the globalization of capital markets, trade, and manufacturing. In turn, globalization reshaped the industry's structure from vertical integration to a collection of horizontally grouped firms that seek advantages around the world in labor markets, government incentives, and capital markets. As a result, a substantial number of U.S. fabrication plants migrated to other countries, particularly in Asia, and foreign firms in Asia and Europe have become tough competition for the U.S. market.

Globalization also helped dramatically boost the industry's growth since the significant price reductions brought about by economies of scale and competitive labor rates helped to fuel further consumer demand around the world. Further, growing prosperity in lower wage regions opened large new markets for semiconductor products as workers sought previously unattainable goods.

Globalization forced U.S. firms to become efficient and innovative in order to survive. For example, in the 1980's, Japanese firms built a substantial DRAM chip manufacturing capability that significantly eroded Intel's market leadership. This led to charges of unfair dumping of products below production cost (SIA, 2006). Despite strong U.S. attempts to regain the advantage through trade negotiations, Intel eventually abandoned the memory chip market, but then rapidly established primacy in the extremely successful microprocessor market. This

chapter in the industry's history provides a significant lesson in the value of continual innovation over reliance on government protectionism or intervention.

## Current Conditions

The consumer electronics sector drives the market now, and military and industrial applications take a back seat. Tremendous advances in semiconductor technology enable continual advances in miniaturized consumer devices with rapidly improving capabilities at a lower cost. The challenges of this consumer driven market were well illustrated by an industry official in India who commented that the typical consumer, a teenager he called "Suzy," wanted four things in a new electronics product: a single device with a huge memory capacity that integrated every possible function, small enough to fit under her hat, able to run all day without recharging, with a price tag under $100 in the industrialized nations, and less than $25 in poorer areas (Anonymous industry interviews, May 2006).

### *Industry Trends*

Moore's Law characterizes the semiconductor industry's sustained record of producing ever-smaller and cheaper chips with greater speeds and processing power. Originally stated by Gordon Moore in 1965, it predicted that the density of transistors on an integrated circuit would double every 18 – 24 months (Intel, 2006). Industry groups such as the International Technology Roadmap for Semiconductors (ITRS) attempt to identify and coordinate the advances needed across industry sectors in order to maintain pace with Moore's Law (ITRS, 2005). Each leap in miniaturization technology enables smaller feature sizes. However, physical limits imposed by the size of the component atoms could possibly be reached in the next few decades if the technology continues to rely on Complementary Metal-Oxide Semiconductor (CMOS) processes (Braun, 2004).

Some experts predict that the relevance of Moore's Law will diminish in the near term due to the significantly higher capital investment required for each advance and diminishing practical gains from further miniaturization rather than any particular technological roadblocks (ITRS, 2005). Each new generation requires a capital investment of several billion dollars for tremendously complex fabrication systems, which have a short useful lifetime since the next generation of advanced technology is typically only a few years away.

While initial large capital investments are a significant barrier to entry for new semiconductor firms, venture capital is readily available in the U.S. for promising projects. Successful young firms may raise additional capital by selling stock in an initial public offering, though in recent years most are instead acquired by larger firms (Anonymous interview, April 2005).

The rapid pace of innovation, huge amounts of periodic capital investment, and sudden changes in consumer demand as new technology is introduced all contribute to cyclical market conditions, and large swings in profitability from year to year are not unusual. Currently, analysts consider the industry to be in a profitable phase fueled in great part by strong demand for consumer devices.

### *Profitability and Performance*

The U.S. semiconductor industry, though highly cyclical, achieved strong growth and profit margins in recent years. The industry reported revenues of $126.23 billion in 2004, and increased to $131.85 billion for 2005. Average sales grew by 15.6 percent, and the average return on equity last year was 6.9 percent. The industry's average net profit margin was 7.2 percent, and the average debt to equity ratio was very low (.08). (IBIS World 2005).

Revenues of U.S. owned chip companies account for almost half of global semiconductor sales and over three-quarters of U.S. owned chip-manufacturing capacity is located on U.S. soil (SIA, 2005). Overall semiconductor sales in the U.S. were $39.1 billion in 2004, the third consecutive year of market growth. Even with this growth, U.S.-based companies are experiencing a steady loss of the domestic and global semiconductor market share to foreign competitors (Mergent, 2005).

## Industry Challenges Affecting U.S. National Security

### *Overseas Industry Migration and Foreign Competition*

The efficiencies enabled by globalization led many U.S. firms to relocate their operations overseas in pursuit of advantages, including lower labor costs, more favorable tax and regulatory climates, or locations closer to markets. Some countries provide large incentives to lure foreign investment, such as lucrative tax breaks in China, India, and Korea for research and development costs (R&D Credit Coalition, 2006). According to the Semiconductor Industry Association, the cost difference over ten years for a 300 mm fab plant between the U.S. and China is about $1 billion, and most of this difference is due to tax breaks and grants (SIA, 2005). Foreign countries also offer more subtle incentives to attract new firms. The Software Technology Park of India (STPI), for example, acts as a "front end" provider for new firms on behalf of the government, and is a single point of contact for establishing infrastructure support and navigating complex trade and tax requirements (STPI, 2006).

While numerous fab-less design firms operate in the U.S., these firms also feel significant pressure from overseas competition, particularly in India, where about 8,000 design engineers worked in 2004 for significantly lower wages than their American counterparts (James, 2006). Industry officials the group interviewed in India said that the recent high tech boom there caused salaries for those in the industry to double in the past 10 years, and that competition for highly skilled workers was increasing rapidly. Yet the cost structure for this workforce is still only about one third that of similar U.S. workers. Analysts also indicated the number of English-speaking engineering graduates there is expected to grow about 20 percent per year, though one official stated that about 60 percent of new graduates were not suited for immediate employment due to shortfalls in their experience and quality of education (Anonymous industry interviews, May 2006). Officials were also concerned that the rapidly growing income divide between the industry workers and the impoverished lower class majority in high tech areas like Bangalore could lead to significant social unrest.

Some industry analysts claim the overseas migration of U.S. firms and the strong competition posed by foreign firms are a significant risk to U.S. economic security since the semiconductor industry has been a crucial enabler of recent economic growth and productivity advances. These analysts recommend strong government intervention to sustain a globally

competitive design and fabrication capability in the U.S. (Spencer, 2004). Later sections of this paper will analyze these recommendations.

### *National Defense Concerns*

Several reports commissioned by DoD highlight risks to national security posed by the loss of guaranteed access to chip manufacturers located on U.S. soil (Defense Science Board, 2005 and Joint U.S.-UK Task Force, 2006). Since DoD now accounts for less than 2 percent of annual global chip purchases, it has little ability to influence manufacturers, and must purchase commercial products, or must maintain a dedicated capability for building custom-made devices. Later sections in the study discuss this problem in detail.

### *Human Capital Challenges*

Along with the migration of semiconductor facilities, industry observers are also concerned that the U.S. is losing its share of the skilled engineers and scientists needed to drive innovation in this complex technical field. For example, the number of bachelor degrees in engineering fields has remained static in the U.S. in the past ten years, while Asian countries produce at least six times as many engineers per year (Spencer, 2004). Further, many of the foreign students who earn advanced technical degrees in the U.S. do not remain here, either due to immigration limitations or due to improving opportunities in their home country. China and Taiwan both provide substantial incentives for highly educated workers to return home (Spencer, 2004). This topic is discussed further later in the study.

### *Decline in Research Funding*

Semiconductor industry groups claim that reduced federal government funding for basic research at a time when foreign competitors are increasing research support is also threatening the domestic industry’s future. For example, federal funding for physical sciences research as a percentage of GDP is about half the 1970 value (SIA Research Group, 2006). Analysts point out that historically, basic government research enabled most major technological advances, and argue that the industry cannot continue to be competitive without greater government support (Spencer, 2004). This topic will be discussed in detail below.

## Industry Outlook

### *Consumer Electronics Key to Near-Term Growth*

Communications, gaming, and other commercial products will continue to drive global market growth in the near-term. Consumer demand and not the defense industry now drives most new advances. Cell phones provide an excellent example of consumer-driven growth; the integration of multiple technologies into handsets, including wireless networks, global positioning, Bluetooth, and digital cameras led to a dramatic increase in the semiconductor content per device. This miniaturization and rapidly increasing sophistication continues to fuel booming global demand for the latest designs.

***Long-term Outlook***

Most industry groups agree that CMOS technology will predominate for at least the next ten years, with higher speeds, lower power, and smaller costs achieved by scaling chip features to ever-smaller dimensions. Immersion lithography and extreme ultraviolet lithography processes for transferring the circuit pattern onto the silicon wafer will etch features that approach atomic dimensions (National Research Council, 2003). As discussed earlier, the escalating costs for each technology leap may eventually make further advances uneconomical since, even for memory and processor chips, the resulting gains may not be worth the cost. Even now, some applications may have reached practical limits for miniaturization; as one analyst wrote, "Field Programmable Gate Arrays are going to 65nm next year, but 65nm will not be a smaller die than 90nm and it won't use less power than 90nm, so the only benefit will be speed…but 90 percent of FPGA applications are happy with the speed. So why are they moving to 65nm?" (Manners, 2005, ¶ 5).

Foundries will continue to be a major force. One official estimated that about 20 percent of the global semiconductor market is outsourced today, and he expected the number to grow significantly (Anonymous industry interviews, May 2006). These firms gather fabrication orders from around the globe, and can produce huge orders for millions of chips. Alternatively, for a premium in unit costs, they can combine many customers' small orders to form a single production run. These highly profitable firms preserve the ability to recapitalize as technology progresses, something smaller firms cannot afford to do. Several foundries the group visited reported spending about $3 billion per year on capital costs. As the group observed, these firms are most likely to operate in countries with low cost structures, and frequently benefit from "cluster effects" by being located in government supported technology parks, complete with housing facilities and other amenities that provide a significantly higher standard of living than is seen outside the park gates. Officials from one foundry told the group that firms operating in the U.S. need to generate a 40 percent gross margin due to high labor and overhead costs, while firms in Asia can typically operate on far lower margins (Anonymous industry interviews, May 2006).

Some analysts are concerned that the overseas migration of many fabrication plants will cause the U.S. to lose its leading industry position, and claim that separation between U.S. based design houses and the foreign foundries will cause a loss of understanding and influence in the manufacturing process. Other analysts considered that remote cooperation was adequate to maintain influence through internet communications, software tools, and on-site visits. However, these analysts also noted that the majority of the profit is taken by the foundry, while the design house likely only earns a small share (Anonymous industry interview, May 2006). One official in India worried that, though his country could easily design the next generation of profitable devices for domestic consumption, there were not yet fabrication plants there capable of producing them, and most profit would go to overseas producers (Anonymous industry interviews, May 2006).

One frequently cited successor to silicon-based semiconductors is nanotechnology, which may provide the best chance for keeping Moore's Law on track. This poorly defined term encompasses a broad range of applications, any one of which could dramatically alter or replace traditional semiconductor designs. For example, microelectromechanical systems (MEMS) are microscopic devices that typically include moving parts; other applications include using carbon nanotubes as thin as several atomic diameters as components in semiconductor devices or in

batteries (Fishbine, 2002). The tremendously small dimensions involved may require new manufacturing processes for self-assembly at the atomic or molecular level, though traditional CMOS processes could be used to create a "scaffold" for the assembly (Braun, 2004). Nanotechnology is expected to bridge numerous disciplines – including electronics, IT, biotechnology, and quantum physics, and a significant amount of basic research is required before this new field can achieve commercial application.

***U.S. industry long-term outlook.***

As discussed earlier, the U.S. semiconductor industry, though cyclic, is performing well, and given its current strong position in world semiconductor markets, should continue to do so in the near-term. Its long-term outlook, and its long-term ability to support U.S. national security requirements depends on a number of variables, including whether U.S. companies can retain leadership in innovation in the development of nanotechnology, and whether they can remain competitive in the increasingly globalized market by moving their facilities overseas or by finding ways to remain profitable on U.S. soil. During interviews with the study group, industry leaders repeatedly stated that U.S. government policies will be essential to their firms' ability to remain competitive for the long-term (Anonymous industry interviews, April 2006).

Officials from overseas semiconductor firms frequently stated they considered the U.S. to hold a significant lead in innovation. One official commented that firms in his country relied on U.S. innovation for their prosperity, while they in turn held the advantage in remaining profitable in an extremely competitive environment with ever-shrinking profit margins. Specific U.S. strengths mentioned were innovations in wireless technology, analog chip design, and system on a chip (SoC) design (Anonymous industry interview, May 2006).

The remaining sections of this paper examine the government's various policy options, and provide balanced recommendations for helping to ensure the industry's long-term success without resorting to harmful subsidies or other artificial measures.

## Government Roles

In the globalized marketplace, the U.S. government's role in promoting the semiconductor industry should focus on those measures that promote competitiveness without erecting artificial barriers to free and fair trade. Such measures include aggressively promoting free trade practices, cultivating innovation by investing in advanced research programs, and by helping to promote advanced education in science and engineering fields. Out-dated government export regulations that hinder free trade should be reviewed and streamlined where appropriate. Tax laws and Sarbanes Oxley accounting regulations should also be reviewed and corrected in those areas that impose an unfair disadvantage to the industry.

***Promoting free trade***

A stable international trade system free of artificial barriers and subsidies is essential to the U.S. semiconductor industry's success, and the government plays an essential role in promoting free trade with global partners. Beyond tariffs and direct subsidies, subtle differences in competitor nations' tax laws, tax holidays, capital asset depreciation rules, provisions for low

interest loans, and training grants can also contribute to an unfair advantage. The government must thus continually assess which measures constitute an unfair advantage, and which are simply good practices for promoting economic health. As discussed earlier, Intel demonstrated in the 1980's that trade negotiations will not always succeed, and the industry must rely on innovation to maintain the lead.

***Innovation & education***

Both the Congress and Administration recently recognized the need to boost the competitiveness of U.S. firms in the global market. The National Innovation Act (NIA), Protecting America's Competitive Edge (PACE) Act, and the American Competitiveness Initiative (ACI) are competing proposals for boosting education in math, sciences, and engineering fields, and for increasing funding in basic research activities. Although the proposals vary in their specific details, each would provide for similar outcomes. Enactment of any of these three proposals would help to improve U.S. competitiveness, not only in the semiconductor industry, but also in every scientific and technical field. However, additional discretionary spending in an era of high deficit budgets makes passage uncertain.

***Taxation policy***

Several U.S. tax laws have a negative impact on semiconductor industry recapitalization and R&D efforts. Revising existing laws affecting depreciation and foreign source income may help to encourage U.S. semiconductor firms to recapitalize within the U.S. Current rules require semiconductor companies to depreciate manufacturing equipment over a five-year period, but much of the equipment has a useful economic life of only about three years (IBIS World, 2006). Existing rules for foreign source income frequently tax repatriated profits, a factor inducing firms to leave profits overseas (SIA, 2005).

Many foreign nations offer significant tax credits for R&D efforts, but a temporary U.S. credit expired in 2005. China offers foreign investors a 150 percent deduction for R&D expenditures as long as R&D spending increases by 10 percent from the previous year. India offers a 100 percent deduction of profits for 10 years for R&D, while Singapore provides U.S. companies a 5-year tax holiday for foreign income earned for Singapore-based research (R&D Credit Coalition International Tax Incentives, 2006). Efforts to make the U.S. tax credit permanent are contained in the pending NIA, PACE, and ACI proposals discussed earlier, and enactment would encourage U.S. firms to perform research, spur innovation, and sustain domestic economic growth.

***Export controls***

U.S. export regulations affect the semiconductor industry's competitive advantage in sales to China and other potentially hostile nations for some restricted products that are readily available from competing nations. The U.S. controls exports on certain equipment and materials used to make semiconductors due to national security or foreign policy concerns. The government participates in numerous informal multilateral export agreements to help control the sale of sensitive technologies, including the Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies. While this informal agreement

requires participating nations to inform other participants of approvals and denials of export licenses for sensitive items, other nations cannot veto a sale (GAO, 2002, p.8).

Several industry representatives reported U.S. efforts to control the transfer of dual-use semiconductor technology to China are failing under the Wassenaar Arrangement (Anonymous industry interviews, April 2006). While U.S. semiconductor companies must complete a lengthy process to obtain export licenses for sensitive items, industry representatives claim foreign competitors are able to export more efficiently within their nation's interpretation of the voluntary Wassenaar Arrangement. This may enable overseas competitors to seize market share at the expense of U.S. producers. Further, the Government Accounting Office reported foreign exports of cutting-edge semiconductor technology have helped China to close the semiconductor technology gap with the U.S. to less than two years (GAO, 2002).

***Accounting Rules***

The Sarbanes-Oxley (SOX) Act of 2002 levied significant new accounting rules on public corporations following a series of major corporate fraud scandals. Industry leaders the group interviewed reported that once these rules are fully in effect they will disproportionately burden small companies, causing highly innovative semiconductor firms to divert significant resources away from technical innovation. Since young firms must be SOX compliant by 2007 in order to be acquired by a larger public firm or in order to become an independent publicly traded firm, these new rules may hinder future growth in a sector that helped drive several decades of domestic economic prosperity. Further, the rules cause significant new expenses for larger corporations not imposed by foreign nations. At this point, it is too soon to measure the effects of the new SOX rules, and on-going analysis is required to ensure their public benefits outweigh the burden to industry.

New accounting rules adopted by the Financial Accounting Standards Board (FASB) require companies to begin listing stock options as expenses on financial reports (Chappell, 2005). The industry had used stock options extensively to help recruit the best engineering talent and to fuel innovation. The new rules require companies to put a dollar figure on the future value of their employee stock options (Chappell, 2005). Industry representatives interviewed by the group argued against the requirement since they predict U.S. companies may be less inclined now to offer stock options, and subsequently talent may be lost to aggressive foreign competition (Anonymous interviews, 2006). The impact of the new stock option rules on the U.S. industry should be carefully monitored, particularly for small companies, to ensure that innovation and global competitiveness are not being unduly affected.

***Defense acquisition***

DoD must maintain its strategic capability through access to trusted semiconductor design and fabrication processes. Due to its miniscule market share, DoD can no longer influence manufacturers and either must purchase commercial products or must maintain a dedicated capability for building custom-made devices. Government intervention to preserve strategic access to semiconductor components is clearly needed to ensure DoD unique devices can be built without compromising their technology, though every effort should be made to minimize the cost by using COTS devices whenever possible. Collaborating with industry is the best way to address any immediate concerns. The Trusted Foundry Program will help address the short-term

needs; however, DoD should consider expanding its relations with industry over the long term. Defense electronics acquisition will be discussed in more detail later in the paper.

## Human Capital and Competiveness Challenges

Most industry representatives interviewed by the study group were concerned the U.S. is not producing enough graduates in advanced science and engineering fields to remain competitive in the global arena. One U.S. firm stated it could only fill 1280 of 1500 openings for engineers last year (Anonymous interviews, April 2006). The following sections summarize steps needed to improve the nation's ability to train, attract, and retain the best human capital available; such steps are essential for maintaining leadership in innovation and economic productivity – not only for the semiconductor industry, but also for every industry.

### *Education System Challenges*

While fewer U.S. students are earning undergraduate and graduate degrees for science, technology, engineering, and mathematics (STEM) disciplines, China is producing rapidly growing numbers: 350,000 engineers in 2003 and 500,000 in 2004 (SIA, 2006). China is now producing about the same number of technical graduates per capita as the U.S., and will have a vastly larger pool of highly trained talent within a few years should current trends continue. India also has a rapidly expanding pool of graduates with advanced technical degrees; industry officials there commented that most Indian families place a higher premium on their children's education than they do on living in a good home or buying a car. Further, industry members there work closely with the education system to ensure school programs are kept updated in the rapidly changing high tech world (Anonymous industry interviews, May 2006).

Additionally, the public education system in the U.S. is less effective when compared to systems in many other industrial nations. A shortage of qualified K-12 math and science teachers led many of the nation's 15,000 school districts to hire uncertified or poorly qualified teachers (Rising above the Gathering Storm, 2006). A 2005 Gallup poll indicated that more than 50 percent of U.S. respondents were either "completely dissatisfied" or "somewhat dissatisfied" with the quality of public education, and indicated an improvement in teacher qualification was the critical element needed to help correct the problem (Gallup, 2005). The pending national competitiveness legislation discussed earlier may help to reverse these disturbing trends.

### *U.S. Immigration Policies for Technical Talent*

One of five scientists and engineers in the United States was born in another country (AEA, 2005). Following the September 11, 2001 terrorist attacks, the U.S. put significantly tighter controls on immigration policies, and as a result, fewer foreign students were able to attend U.S. universities, and fewer foreign graduates with advanced technical degrees were able to immigrate here. It thus became even more difficult for U.S. firms to hire the needed technical talent to sustain growth and innovation. One analyst stated, "Our immigration policy took a giant step backward because of fears associated with September 11. Making it hard for graduate students to come here does not make America safer. It makes us weaker…" (Business Week, 2004, ¶4). Industry representatives interviewed by the group consistently advocated loosening

restrictions on H-1B visas and Employment-Based (EB) Green Cards for technically trained foreigners in order to help alleviate the shortage of domestic high tech graduates by widening the pool of foreign-born talent available to U.S. firms (Anonymous Interviews, April 2006).

The H-1B visa provides temporary entry under a nonimmigrant classification for a foreign citizen sponsored by an employer in a specialty occupation such as the semiconductor industry (U.S. Citizenship and Immigration Services, 2006). The H-1B visa ceiling is currently set at 65,000 visas per year, with an additional 20,000 exemptions for foreign workers with U.S.-earned advanced degrees. Congress temporarily increased the limitation to 195,000 between 2001 and 2003 and a similar, permanent expansion would greatly assist the semiconductor industry to hire the best technically trained talent in adequate numbers. Further, such an expansion could also help to boost domestic job creation. For example, one semiconductor firm the group interviewed stated that one person working for the company under the H-1B visa program developed a new process that is now responsible for the creation of 400 new jobs (Anonymous industry interviews, May 2006).

Unlike H-1B visas, EB green cards apply to employer-sponsored foreign nationals seeking permanent residence (Compete America, 2006). One industry representative interviewed by the group suggested an EB green card be stapled to every advanced technical degree earned by a foreigner in the United States – most foreign graduates are forced to leave the U.S. shortly after they finish school due to the existing difficulties encountered when attempting to immigrate (Anonymous industry interviews, April 2006).

## Defense Policy Concerns

### *Introduction*

As the U.S. defense share of global semiconductor manufacturing continues to decrease, DoD must carefully manage component obsolescence, must ensure the availability of trusted manufacturers, and must maintain a surge capacity to support national security needs. One of the major concerns for strategic policy makers is the offshore migration of semiconductor manufacturing (DSB Task Force, 2005). The growth of semiconductor fabrication facilities in Asia led to a growing dependence on foreign suppliers for defense industry integrated circuits. In fact, DoD is the most heavily outsourced organization in the federal government, with an increasing amount of research and development (R&D) and fabrication performed overseas (C. Wilson, 2005). One U.S. defense contractor official interviewed by the group acknowledged a dependence on foreign-supplied silicon-base integrated circuits (IC) and considered that some defense industry suppliers are outsourced to the point where it is difficult, if not impossible, to track the pedigree of some ICs incorporated into defense systems (Anonymous industry interview, March 2006).

Since the semiconductor industry is now driven almost entirely by the strong demand for consumer products, the defense industry's miniscule demand for electronic components no longer commands any significant influence. For example, in 2000, the defense aerospace industry commanded less than one percent of its market, compared to a seven percent share in 1984 (Condra, 1999). The majority of electronic components manufacturers have divested their defense related customers in favor of the high volume commercial market.

With more constrained defense budgets, best value has been the driving factor for most government purchases. Since the market has replaced the government as the primary driver for technology development, new weapon platforms become quickly outdated by new technology

advances, and system obsolescence and non-availability of repair parts is a rapidly growing problem. Commercial defense suppliers are typically quick to abandon legacy chipset production in favor of profitable new commercial technology. This creates niche markets for the expensive production of small orders of obsolete defense parts.

The defense acquisition system has tended towards providing detailed systems parameter requirements only for a platform’s overall functionality and performance, while leaving other parameters to the contractor’s discretion, such as material suppliers, parts manufacturers, or in-house testing capabilities. This business model may break down when producing sensitive, classified, high value, or advanced technology items.

Another DoD concern is mission creep of military specifications (Mil Spec) for electronics components. When feasible, the use of Commercial off the Shelf (COTS) or Modified off the Shelf (MOTS) products is preferred since few commercial vendors find it profitable to produce Mil Spec electronic components. However, most commercial semiconductors sold for commercial use do not require extensive environmental hardening. Most military systems must operate in a wide range of environmental conditions, and certification for operations in extreme conditions invokes a long list of tests, often including temperature variance, shock and vibrations abuse, tamper resistance, humidity, varying barometric pressures, and salt corrosion resistance (DMEA, 2002).

Recent advances in commercial semiconductor technology show that the latest “cutting edge” technology will likely appear first in the commercial market rather than in the defense market. The tremendous decrease in circuit feature sizes, often as small as 65 nanometers,  now make such circuits in effect radiation hardened (“rad-hard”) by default since radiation can pass through the circuit with less chance of encountering or damaging the smaller features (DMEA, 2006). Some manufacturers are concerned that such technology could be classified as “dual-use” and be placed under export restrictions as sensitive defense technology, even though it is widely available on the commercial market. (Anonymous industry interviews, April 2006).

### *Defense System Component Obsolescence*

Component obsolescence in defense systems is a growing problem for both the United States and its allies. Until recently, military electronic components were designed and procured under two basic assumptions: that there was a ready supply of qualified components, and that the designs would remain stable for long periods (Condra, 1999).

Market forces drive obsolescence: when an item is no longer economical to produce, manufacturers stop producing it (DMEA, 2006). Defense market demand cannot compete with the exploding global demand for commercial products, including cell phones, personal data assistants, personal computers, and audio-video devices - all being produced on very short product cycles. Military weapons systems are procured on cycles often lasting several decades, and managers usually do not have the luxury of updating designs every two to three years in order to reset the obsolescence clock and keep abreast of the latest technology.

There does not appear to be a single “silver bullet” solution to the component obsolescence problem; DoD relies on a number of methods, including employment of trusted foundries, production by Defense Microelectronics Activity (DMEA), reverse engineering, technology insertion, design freezes, lifetime buys and commercial standard replacements. Additionally, systems designs that incorporate modularity or open architectures better support new technology insertions and are more capable of avoiding obsolescence problems.

The Defense Microelectronics Activity (DMEA) was established by the Secretary of Defense as the Executive Agent for microelectronics obsolescence, and reports directly to the Deputy Undersecretary of Defense for Logistics and Material Readiness. (DMEA, 2006). DMEA attempts to leverage new microelectronics technologies to improve defense system reliability and maintainability, enhance capability and performance, and mitigate the effects of rapid obsolescence. DMEA's Advanced Reconfigurable Manufacturing for Semiconductors (ARMS) serves as a flexible foundry that can produce form, fit and functionally equivalent integrated circuits (DMEA, 2006). Some defense contractors rely on DMEA to produce a chip that is no longer available on the open market. DMEA is also capable of redesigning and recreating manufacturing processes that are no longer available in the semiconductor industry. The ARMS approach, which concentrates on the component redesign vice physically stockpiling replacements, appears to be a promising method for producing obsolete parts, though it relies on an expensive and inherently inefficient (by industry standards) government production facility.

Although lifetime buys of replacement parts will solve the immediate problem of keeping systems operational, this method can be very expensive due to storage costs and the cost of re-establishing the component integrity. There is also the potential that a purchased assembly could contain obsolete sub-components, negating the utility of the lifetime buy (Beck, 2003).

Defense officials from one nation the group interviewed compared two general obsolescence strategies: lifetime buys of spare parts, and periodic system replacement. While the lifetime buy strategy was typically cheaper, this method was considered inferior since the critical ability to update the system with new technology was lost. In one case study presented to the group, four specific strategies were considered: lifetime buy of repair parts, system replacement after five years, mid-life replacement at 7.5 years, and piecemeal replacement at system failure. While the lifetime buy and piecemeal replacement methods were cheapest, replacement at 7.5 years was most beneficial when weighing the value of technical updates, and cost about one-third more than the cheapest methods, while replacement at five years cost twice as much (Anonymous industry interviews, May 2006).

### *DoD Approaches to Trust*

The term "trust" in the commercial market is concerned with verifying design and function to eliminate unintentional flaws or inefficiencies in IC design and to protect Intellectual Property (IP) elements. DoD and other national security related applications must expand the trust concept to include providing for the security of critical designs and eliminating intentional flaws, or "Trojan Horses" that may degrade or compromise the function of ICs (DSB Task Force).

DoD and defense contractors are moving away from using Application Specific Integrated Circuits (ASIC) to Structured ASICs and Field Programmable Gate Array (FPGA) circuits. An ASIC chip is one designed for a specific purpose and is generally applied to a discrete operation that is hard to integrate into other designs. As a result, ASICs are generally produced in lower numbers, with a higher unit cost (Gain, 2003). Additionally, if the ASIC design is compromised, it may be easier to determine its sensitive function (DSB Task Force, 2006). FPGAs allow DoD users to manage the classified design elements outside of the commercial industry's control (Joint DSB/DSAC Task Force, 2006). This adds to the level of trust, but has the drawback of generally lower performance when compared to ASICs (Morris, 2006). A hybrid between ASIC and FPGA designs, termed Structured ASIC, allows a standard

chip design to be modified late in the fabrication process to add specific functionality. This allows for tighter control of the sensitive design elements to a discrete stage in the fabrication process (DSB Task Force; 2005). This has the additional advantage of reducing design and fabrication time and costs (Joint DSB/DSAC Task Force, 2006; Morris, 2006).

Even with the introduction of programmable devices and structured ASICs, DoD must maintain access to trusted chip suppliers for certain applications (Anonymous industry interview, March 2006). A joint initiative between the National Security Agency (NSA) and DoD known as the Trusted Foundry Program may help to fill the void caused by the impending closure of the NSA-operated foundry and by the overseas migration of many commercial fabrication facilities. The government inaugurated the program with a 10-year contract with IBM for access to state-of-the-art IC manufacturing. The arrangement involves a “take-or-pay” contract worth up to $600 million in which the government guarantees a minimum number of chips for production but pays a user fee regardless of how many orders accrue (Manzullo, 2005). IBM was certified to produce chips up to a specified classification level to eliminate any issues of trust (Anonymous industry interview, March 2006). This program provides the government with the flexibility of low-to-medium rate production of sensitive ICs while providing access to leading-edge technology (Manzullo, 2005). Other firms also expressed their intent to join the Trusted Foundry Program (Anonymous industry interviews, April 2006). Some experts warn, however, that this is only a short-term solution for a larger problem, and that the continued overseas migration of fabs could eventually shrink or eliminate the availability of trusted foundries (DSB Task Force, 2005).

DoD is working in other areas to ensure the availability of trusted circuits for weapons systems acquisition programs. DoD has designated the Air Force as the Executive Agent for the Anti-Tamper program, and is charged to ensure that that ICs used in new systems meet required standards for trust and reliability. Progress is continuing in this area as new guidance is being developed; however, there is room for improvement as program managers struggle to make room in their budgets to support Anti-Tamper compliance (GAO Report, 2004; Anonymous industry interviews March 2006).

In developing future options to ensure access to trusted foundries, DoD should also review how the commercial market is handling the same issue today. Commercial foundry customers frequently face significant concerns for protection of intellectual property (IP) since the compromise of sensitive commercial IP could threaten a firm’s future. Several foundries the group visited explained how many customers address this issue. Many firms only out-source “low-end” designs to the foundry, particularly if the foundry were located in a high-risk area such as China, and produce the “high-end” designs in house. Foundries also recognize that their future depends on maintaining the customer’s trust, and attempt to build trust by employing third party audit firms with engineering backgrounds to perform detailed independent reviews of the entire process, to include how communications between the foundry and customers are protected, and how wafer scraps are accounted for prior to destruction. Coded systems are frequently used to preserve the customer’s anonymity during manufacturing, with only a small number of senior employees trusted with the identification codes on a need to know basis. Customers frequently station representatives at the foundry to monitor manufacturing processes and IP protection (Anonymous industry interview, May 2006). Some DoD components might be manufactured under similar IP protection processes when the chip design’s sensitivity is reasonably low, or if the sensitive technology could be added later through software or manufacturing steps in a secure facility.

### *Other Challenges to DoD Electronics Requirements*

Beyond trust problems, DoD must contend with numerous other issues to ensure a dependable supply of ICs. For example, the military must have enough flexibility in its procurement process to account for mobilization and surge capacity in times of war. The Trusted Foundry Program and the DMEA foundry would both be elements in this response. Additionally, the Defense Logistics Agency maintains a program called the Diminishing Sources and Material Shortages Program that assesses the stock of critical components for war fighting needs (Johnson & Robinson, 2003). This program strives to ensure wartime stocks of critical items with a focus on hard to get and discontinued components. The program also searches for alternate sources of components no longer produced. One of the largest challenges in the defense electronics sector for mobilization and surge capacity is in the area of expendable microelectronics that support precision munitions (Gain, 2003). No clear analysis of surge capacity in this vital area was available to the study group, and this may require additional DoD study to ensure an adequate supply would be available in time of national emergency.

### *Defense Policies and the Semiconductor Industry: Summary*

One critical advantage that DoD has for now is a strong U.S. commercial infrastructure for producing the complex programmable logic circuits used in many weapons systems. This segment of the semiconductor market has not yet seen the same level of offshore migration that characterizes the more commercialized products (Joint DSB/DSAC Task Force, 2006). While some defense experts have warned of the danger of the overseas migration of fabrication facilities, there is evidence that the U.S. lead in the fabrication of complex programmable logic circuits is secure for now and the supply of these circuits has enough competitors to support military needs (Clendenin, 2005). However, the industry adjusts rapidly to global pressures, and DoD must continually monitor trends to ensure adequate trusted suppliers are still available. The Trusted Foundry Program and DMEA will help provide access to non-commercial chips; however, DoD and other affected government agencies may find it more effective to broaden their relationship with industry. The government used this approach in the mid-1980s when it collaborated with industry to form SEMATECH, a coalition of government and corporate partners focused on sustaining America’s position in the semiconductor industry (Detar, 2005; Science Advisors, 2005). A similar approach today may help to determine the proper long-term solution set for defense semiconductor needs, including whether a means to employ overseas foundries could be developed that maintains a trust level appropriate for the specific component.

## Research and Development Challenges

In an industry dominated by the commercial market, with huge capital investments required for every leap to the next generation of technology, an aggressive Research and Development (R&D) effort is essential. It is thus important to understand what types of R&D the industry is conducting, and to determine the appropriate role for government to help ensure future competitiveness.

### Electronic Industry R&D

R & D efforts in the electronic industry may be grouped into several categories. Basic research projects attempt to answer fundamental questions of sciences or engineering and may not have any immediate application or return on investment. In the long term, however, basic research may achieve fundamental breakthroughs that change an industry and potentially employ millions of people worldwide. On the other hand, applied research (also called development) typically attempts to apply existing technology towards a specific profit-oriented goal. This is critical in the extremely competitive electronics industry, characterized by large profits, significant entry barriers, and low unit costs. Almost 17 percent of the $110 billion industry profits last year were spent on R&D, with the vast majority of that money focused on development (SIA, 2006). Most industry leaders interviewed during the study stated their firms could only focus on developing products intended for the market within the next 2 to 5 years; they usually could not afford to perform longer-term basic research due to the tremendously competitive market (Anonymous industry interviews, May 2006). These industry leaders strongly advocated partnerships with government and universities to perform the basic research needed to sustain long-term competitiveness. As discussed earlier, chip feature sizes are shrinking to the 90 and 65-nanometer range, and analysts predict that within the next 10-15 years, the limits of CMOS miniaturization will be reached as dimensions near as small as the size of atoms. Sustaining the industry's growth and profitability will require significant basic research to achieve breakthroughs in nanotechnology.

### Industry R&D Programs

The industry's collective International Technology Roadmap for Semiconductors (ITRS) attempts to document historical trends and coordinate industry-wide actions needed to achieve future technological advances. The roadmap is global in perspective, and is a key tool for focusing research efforts.

Other organizations help focus the electronic industry's research efforts. Semiconductor Research Corporation (SRC) was formed in 1983 by the industry to help promote the flow of funds to the university research, and has to date awarded more than $500 million in research contracts (SIA, 2006). The Focus Center Research Program (FCRP) is a collective effort by the industry and DoD to help fund long-range basic microelectronics research at U.S. universities. A governing council with representation from all the participating organizations controls this initiative, which attempts to maintain a long-term focus, out to eight years and beyond. FCRP and SCR only represent a small portion of the total research efforts. Numerous consortiums pool their resources to spread the enormous cost of R&D and to share the results. This trend of cooperation will most likely grow due to the mounting costs of R&D.

### Where R&D Money is Spent

Electronic industry research occurs around the world, and frequently moves to areas with large pools of technical talent where the cost structure is lower, such as India. While SRC is based in the U.S., it funds projects in universities worldwide. The Focus Center Research Program operates in four regional research centers to support collaboration with some of the top universities around the country (MARC, 2002).

Numerous countries, including India, China, Taiwan, Japan, and Korea have subsidized advanced research centers at universities and government or industry laboratories. As a result, some of the best and brightest researchers and scientists are working outside the U.S. In Taiwan, for example, the Industrial Technology Research Institute, a non-profit R&D center funded in large part by the government, conducts research in several advanced technology fields with the goal of licensing new technology to new companies. Inventors are awarded 25 percent of the patent's value, a significant incentive. To date, it has helped form 130 new companies, including several semiconductor companies that are today major forces in the global market: TSMC, UMC, TMC, and VIS (ITRI, 2006).

### *Government Role for R&D*

The government has a clear role to encourage basic research, while industry should fund applied research since it stands to directly profit from these efforts in the short term. Further, it is clear most firms cannot afford to perform fundamental research with no immediate hope for a return on investment given the market's tremendous competitive pressures, high recapitalization requirements, and very short product cycle times. As one industry expert told the study group, the R&D "pump" for semiconductor basic research has been "cavitating" since the mid 1980s, and U.S. efforts may be eclipsed by superior efforts overseas (Anonymous industry interviews, March 2006). Industry observers also commented that life sciences research is gaining a growing fraction of available basic research funding and were worried that without significant investment and progress in areas needed to support nanotechnology advancements, the semiconductor industry could falter, hurting one of the most important engines driving the domestic and global economies.

### *R&D: Conclusion*

The overall state of applied research in the electronics industry is strong, but more effort may be needed in promoting basic research. Firms have shown significant cooperation and flexibility to work with competitors to conduct applied research focused on the development and commercialization of new products. The study group heard repeatedly during its interviews that innovation spurred by basic research would continue to be a vital element in future U.S. economic and national security. The long-term and uncertain nature of basic research makes it best suited for public support, and government and industry experts should conduct a careful review to determine whether additional emphasis is warranted to achieve fundamental breakthroughs in nanotechnology fields – and to keep the industry's long-term growth prospects on track. Such a review should encompass other nations' efforts in order to determine whether cooperative efforts are feasible, and whether the U.S. is taking adequate steps relative to competitor nations to retain the lead in innovation.

## Conclusions and Recommendations

### *Cultivate Innovation without Subsidies*

Just as Intel learned that powerful innovation was the key to remaining successful after Japan drove it out of the DRAM market in the 1985, the government should focus on steps that cultivate similar innovation today, without resorting to subsidies or protectionist steps that run counter to free trade principles. Thus, steps to fund or provide incentives for basic research or to encourage research partnerships between industry and universities are important for helping industry to move beyond CMOS processes to nanotechnology. Similarly, programs for encouraging more science and engineering majors and for attracting foreign graduates with advanced degrees to work in the U.S. are vital. Careful reviews should be conducted of policies that may hinder the domestic industry, including Sarbanes-Oxley regulations, stock options accounting rules, and inequities in export requirements under the Wassenaar Arrangement. Government efforts to promote and enforce free trade practices and protect intellectual property are also essential, though firms must recognize such steps may frequently not be successful in the short term, given recent experiences in China and elsewhere.

On the other hand, steps to provide massive, multi-billion dollar subsidies for retaining globally competitive CMOS-based fabrication or design operations on U.S. soil would work against natural economic forces, and would be unlikely to succeed in the end. Only innovation to develop the next level of technology will be successful in sustaining success, and only market forces (and not artificial subsidies) should determine how long CMOS processes can prevail before nanotechnology becomes viable.

### *Make Realistic Defense Provisions*

Just as the Navy was forced to preserve a domestic capability when the U.S. commercial shipbuilding industry was overcome by overseas competition, DoD must maintain a strategic capability for trusted semiconductor design and fabrication processes. A DoD-controlled design and foundry capacity is needed to produce sensitive components that are unique to defense systems for as long as CMOS based chips play a central role in defense technology. In order to minimize the cost, new systems should be developed to use Commercial off the Shelf or Modified off the Shelf chips whenever feasible, using software measures, and other steps to help guarantee security and technical superiority. Given  today's fiscal climate, DoD should review whether trust relationships could be established under some circumstances with selected overseas foundries, perhaps by adding additional software or hardware protections later in the manufacturing process when appropriate.

### *Show Fiscal Restraint*

The steps recommended above support the industry by promoting basic research and education programs, but would require only a fraction of the multi-billion dollar funding needed to artificially sustain commercially viable semiconductor fabrication facilities in the U.S as some industry analysts recommend. These measures also attempt to minimize the defense costs required to maintain a strategic access to semiconductors, though the magnitude of this cost will depend on what level of advanced technology is needed to counter potential adversaries,

including terrorist organizations attempting to gain an asymmetric advantage, or China, which plans to “leap frog” ahead in military strength.

### *Summary*

The semiconductor industry helped to trigger one of the most significant economic, military, and social transformations since the Industrial Revolution, and there is every sign the tremendous rate of technological change will continue apace. Some industry observers have called for government intervention to reverse the migration of U.S. semiconductor fabrication plants overseas, to boost U.S. global competitiveness by funding basic research and to increase the number of college graduates in engineering and science fields. Government intervention to preserve strategic access to semiconductor components is clearly needed to ensure DoD unique devices can be built without compromising their technology, though every effort should be made to minimize the cost by using commercial products whenever possible. Except for these limited defense provisions, actions to artificially counter global semiconductor market forces would not succeed, any more than trade sanctions succeeded in preserving the DRAM market for Intel in 1985. Other actions to cultivate innovation by supporting basic research and by encouraging the development and retention of science and engineering expertise are the best methods for ensuring future success. Overseas industry officials repeatedly expressed admiration for the tremendous power of U.S. innovation, and this strategic capability must continue to be nurtured. Silicon Valley and other U.S. high tech centers have a sustained record of leadership and adaptation, fueled by a robust venture capital system. As Thomas Hartwick wrote in the sole minority opinion for the recent Defense Science Board report that advocated substantial government intervention, “To be more blunt, it is not DoD’s job to revamp the infrastructure of this healthy, robust and very profitable industry…our nation would be better served if government provided the catalyst or leadership (nonfinancial support)…to facilitate a better semiconductor industry long-term strategic plan.” (Defense Science Board, 2005, p. 103).

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